FIRE HISTORY OF TURKEY MOUNTAIN, ARKANSAS

a report prepared for
the National Park Service
Buffalo National River
Harrison, Arkansas

by

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INTRODUCTION

Fire has played an important part in the distribution and structure of vegetation in Ozark ecosystems for thousands of years. Recent suppression efforts have endangered many natural communities which have evolved with more frequent fires. The object of this work is to define the historic fire regime of Turkey Mountain in the Lower Buffalo River Wilderness and to provide management recommendations. A landscape analysis of fire scar distribution as well as a tree-ring analysis of fire scar dates are used to document the fire history of Turkey Mountain, Arkansas.

METHODS

Landscape analysis

Data was taken along 8 transects (Figure 1; Tables 1,2) at intervals of 50 feet in elevation from the base of the slopes around Turkey Mountain. Elevation was determined for data sites using an altimeter with a resolution of 3 feet. Changes in barometric pressure during data acquisition along a transect caused errors elevation estimates in the range of 1% (Transect 1), 7% (Transect 5), and as great as 14% (Transect 4) in total vertical distance. Uncorrected elevation data was used as is, however, because of the impossibility of making accurate and systematic corrections. Also, the robust nature of the fire scar data minimizes the effects of error in elevation data.

At the sites along the each transect data was taken on 1) the number of trees scarred, 2) the total number of trees, 3) aspect, 4) estimated range in tree sizes, 5) tree species, 6) surface bedrock, 7) elevation, 8) and the number of charcoal sightings. As general rule only trees over 6 inches in diameter were counted. In cases where there were very few trees, trees 5 inch in diameter trees were included. Plots were paced off (20 by 20 squares) and boundary trees chosen. Plot size was increased when trees were scarce. Plot size, however, is not relevant to the percentage of trees scarred at each site. The number of trees in the count, however, decreased the variance in estimates of the percentage of trees scarred. Raw data for slope, aspect, trees scarred, elevation, and percent trees scarred is given in Appendix 1.

Dendrochronology

Wedges were cut from 8 live shortleaf pines and cross-sections were cut from 4 pine remnants. Data from five of the eight live pines was used in analysis. Only one of the remnants (TRK01) was cross-dated and was of sufficient quality for use in analysis. Trees were cross-dated by comparison with cores from Turkey Mountain, Leatherwood Creek, and the Current and Piney Rivers in Missouri.

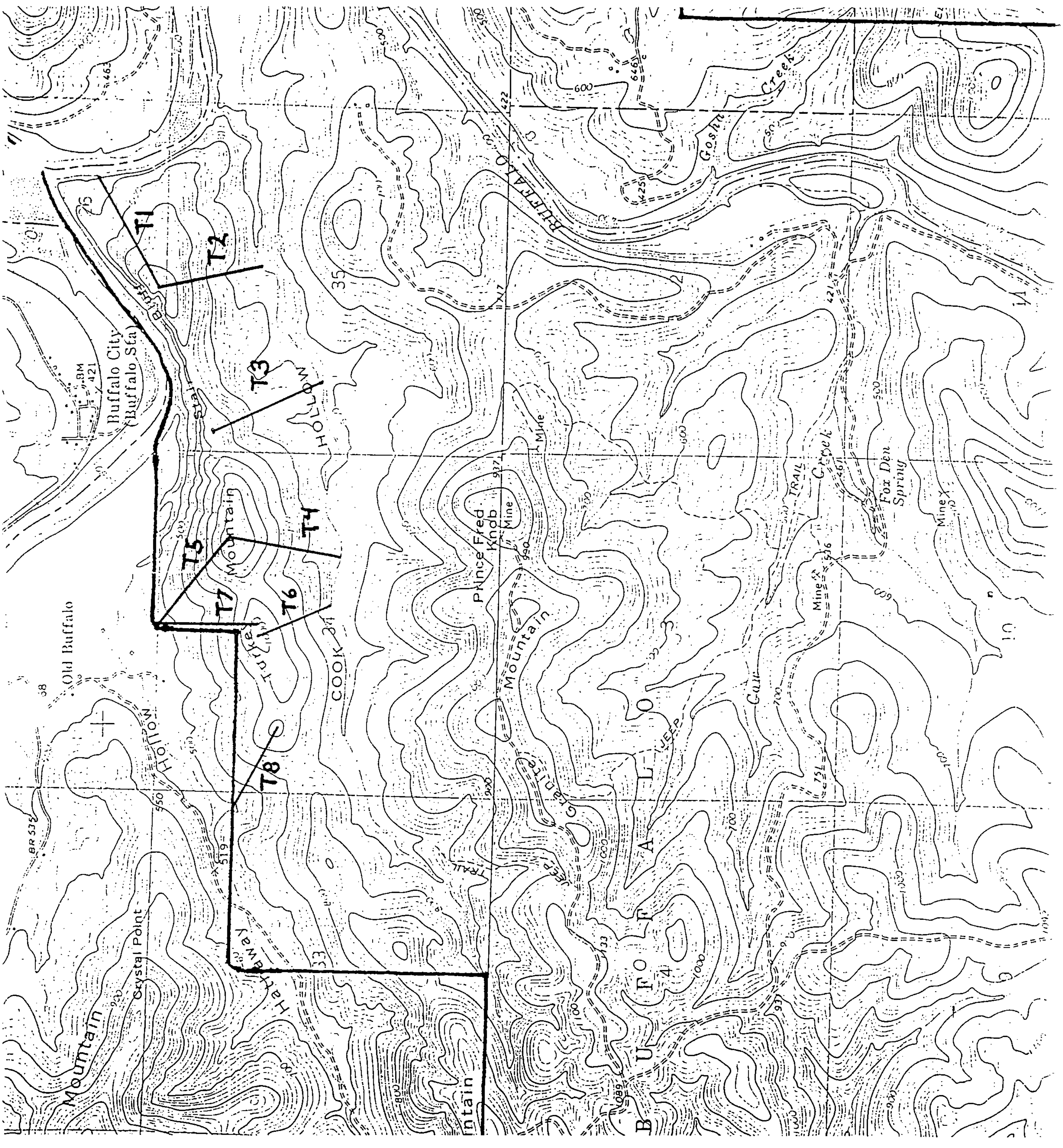

Figure 1. Locations of the 8 Transects on Turkey Mountain used in the landscape analysis.

Limitations

Data on early fires from post trees was limited by the pervasive scarring on this intensity pyrogenic site which has left the vast majority of the old post oaks were rotten or hollow. For example, I cored all the old post oaks near the first saddle up from the Hathaway Trail Head. They were all rotten or hollow although some had no apparent external scars. The few solid trees tend to be either younger trees without scars or located on microsites which limit scarring and bias the record. Also, the cutting of many old live post oaks in the Lower Buffalo Wilderness on the chance they may have a fire scar deep inside may be legal but is not prudent.

It was, however, the lack of old, live shrotleaf pines and remnants that was unexpected and somewhat unusual. Few, in any pines over 150 years old were seen. With the exception of the one 200 year old pine remnant, no other natural pine remnants or stumps were found which had more than 100 rings and these had very few (1-2) scars. The reason for the lack of old pines and remnants is not known. The one old shortleaf pine remnant that was collected did provide critical and important information on fire frequency.

I'm going to
pick up your
pictures

Table 1. Raw data from plot transects. T=transect number, SC=number tress scarred, NT= total number trees, SL=slope (degrees), ELV=elevation (feet above sea level), ASP=aspect (degrees).

T	SC	NT	SL	ELV	ASP
1	00	14	28	523	80
1	02	21	18	545	34
1	03	20	07	595	33
1	04	13	18	645	33
1	06	16	11	695	37
1	02	14	12	745	30
1	04	15	17	795	30
1	06	11	14	845	85
1	04	07	14	895	85
2	03	17	17	429	180
2	04	09	19	481	180
2	04	12	16	534	195
2	06	14	24	585	187
2	06	11	21	633	171
2	06	10	21	687	160
2	04	10	22	730	160
2	05	11	22	780	146
2	09	16	17	830	135
2	05	08	19	880	140
3	00	07	02	460	150
3	07	21	24	510	157
3	07	13	24	560	156
3	09	16	14	610	160
3	07	13	17	660	154
3	07	13	16	710	156
3	11	16	21	760	155
3	11	20	13	810	134
3	05	10	06	849	150
4	01	12	03	534	175
4	05	14	15	584	190
4	03	15	18	634	200
4	05	08	25	684	195
4	09	11	26	734	205
4	06	07	29	784	190
4	05	08	23	834	175
4	08	12	28	884	175
4	09	13	21	934	160
4	05	09	18	984	170
4	12	13	08	1020	190
5	01	17	09	440	315
5	03	14	14	490	315
5	02	11	16	540	320
5	03	10	21	590	310
5	02	08	28	640	305
5	04	09	26	690	305
5	05	09	28	740	310
5	03	10	22	790	315
5	06	11	22	840	315
5	07	10	26	890	310
5	05	12	23	940	290
5	09	13	21	990	310
5	10	16	15	1040	315
6	02	08	00	550	00
6	04	09	21	580	175
6	04	10	18	630	170
6	07	17	19	680	165
6	06	09	14	730	165
6	05	09	21	780	160
6	04	05	23	830	155
6	07	09	22	880	160
6	06	10	11	930	140
6	11	18	05	1020	160
7	01	19	07	460	31
7	05	23	14	510	14
7	04	20	19	560	17
7	06	17	24	610	17
7	05	16	23	660	15
7	04	15	26	710	14
7	02	11	28	760	15
7	07	14	25	810	18
7	07	13	09	880	10
8	02	10	15	530	214
8	02	12	09	580	275
8	04	16	12	630	278
8	06	12	16	680	272
8	04	10	26	730	292
8	03	06	18	780	297
8	08	10	18	830	308
8	07	09	22	880	300
8	06	08	14	930	305

Table 2. Transect plot data: T_P=percent trees scarred, T_R=number trees scarred, T_N=total number trees, T_S=slope,T_L=elevation, T_A=aspect, middle Variable number is transect number.

Variable	N	Minimum	Maximum	Mean	Std Dev
T1P	9	0	57.14	27.27	19.78
T1R	9	0	6.00	3.44	1.94
T1N	9	7.00	21.00	14.55	4.27
T1S	9	7.00	28.00	15.44	5.91
T1L	9	523.00	895.00	698.11	132.04
T1A	9	30.00	85.00	49.66	25.37
T2P	10	17.64	62.50	45.70	13.57
T2R	10	3.00	9.00	5.20	1.68
T2N	10	8.00	17.00	11.80	2.97
T2S	10	16.00	24.00	19.80	2.61
T2L	10	429.00	880.00	656.90	150.87
T2A	10	135.00	195.00	165.40	20.55
T3P	9	0	68.75	47.20	19.89
T3R	9	0	11.00	7.11	3.33
T3N	9	7.00	21.00	14.33	4.47
T3S	9	2.00	24.00	15.22	7.56
T3L	9	460.00	849.00	658.77	134.95
T3A	9	134.00	160.00	152.44	7.61
T4P	11	8.33	92.30	58.21	26.77
T4R	11	1.00	12.00	6.18	3.09
T4N	11	7.00	15.00	11.09	2.70
T4S	11	3.00	29.00	19.45	8.23
T4L	11	534.00	1020.00	782.72	163.76
T4A	11	160.00	205.00	184.09	13.93
T5P	13	5.88	70.00	40.64	20.69
T5R	13	1.00	10.00	4.61	2.75
T5N	13	8.00	17.00	11.53	2.75
T5S	13	9.00	28.00	20.84	5.82
T5L	13	440.00	1040.00	740.00	194.72
T5A	13	290.00	320.00	310.38	7.48
T6P	10	25.00	80.00	55.17	17.54
T6R	10	2.00	11.00	5.60	2.45
T6N	10	5.00	18.00	10.40	4.00
T6S	10	0	23.00	15.40	7.82
T6L	10	550.00	1020.00	761.00	155.23
T6A	10	0	175.00	145.00	51.80
T7P	9	5.26	53.84	29.13	15.50
T7R	9	1.00	7.00	4.55	2.06
T7N	9	11.00	23.00	16.44	3.74
T7S	9	7.00	28.00	19.44	7.69
T7L	9	460.00	880.00	662.22	140.69
T7A	9	10.00	31.00	16.77	5.82
T8P	9	16.66	80.00	48.27	25.01
T8R	9	2.00	8.00	4.66	2.17
T8N	9	6.00	16.00	10.33	2.82
T8S	9	9.00	26.00	16.66	5.12
T8L	9	530.00	930.00	730.00	136.93
T8A	9	214.00	308.00	282.33	28.81

RESULTS AND DISCUSSION

Fire Frequency

For the 223 years of record the mean fire interval was 5.7 years. For the period before 1972 the mean fire free interval was 5.2. The longest fire free interval was 34 (1770-1804) years and the shortest was 1 year. These minimum estimates are based on 54 dated fire scars. The average fire interval for the occurrence of fire in Cook Hollow is probably somewhat lower than this because of the low number of sample trees available. Data from areas with comparable frequencies derived from sentinel pines, such as Blue Spring and Mill Hollow on the Current River, indicate that where sentinel pines have a fire free interval of 5 or 6 years (Table 3) the mean fire free interval for the presence of fire somewhere in the area is about 2 years. This may well be the case for Turkey Mountain. A comparison of fire free intervals calculated from each tree is given in Figure 2.

No fire scars were documented between 1972 and 1993. The recent and replicated period (1953-1971) had a fire free interval of 4.5 years (18 years/4 fires) for the extensive fires that occurred in 1953, 1960, 1963, and 1971. This interval is close to the average fire interval for the last 200 years on Turkey Mountain (Table 3) calculated from Sample TRK01 (6 years).

The low number of fire scars between 1815 and 1840 may indicate a true reduction in fire frequency despite the data being from only one tree. Fire scar data from a post oak savanna 35 miles to the north, the Caney Mountain Wildlife Refuge, showed a similar reduction in fire frequency between 1810 and 1850. Fire frequency in the Ozarks is highly dependent on ignitions from human populations because of the rarity of lightning caused fires. Speculation is that in many areas unsuitable for agriculture, early migration of Native Americans to the area, and their subsequent removal by treaty occurred decades before the areas were settled by European Americans. The Cherokee Tribe left Arkansas by "treaty" in 1828.

The absence of fire scars in the early period, between 1770 and 1804, is week evidence for the absence of fire in the area. The first fire scar on a shortleaf pine requires much more heat than in necessary for subsequent scars. However, the tree was released from competition in 1804 and this could indicate the beginning of a change in vegetation owing to a change in fire frequency and the migration of Cherokees into the area.

The decade with the most fire scars is the 1950's. It appears that around this time the area was burned nearly annually. The fire scars of the 1950's are difficult to date because of the limited amount of callus tissue formed after each

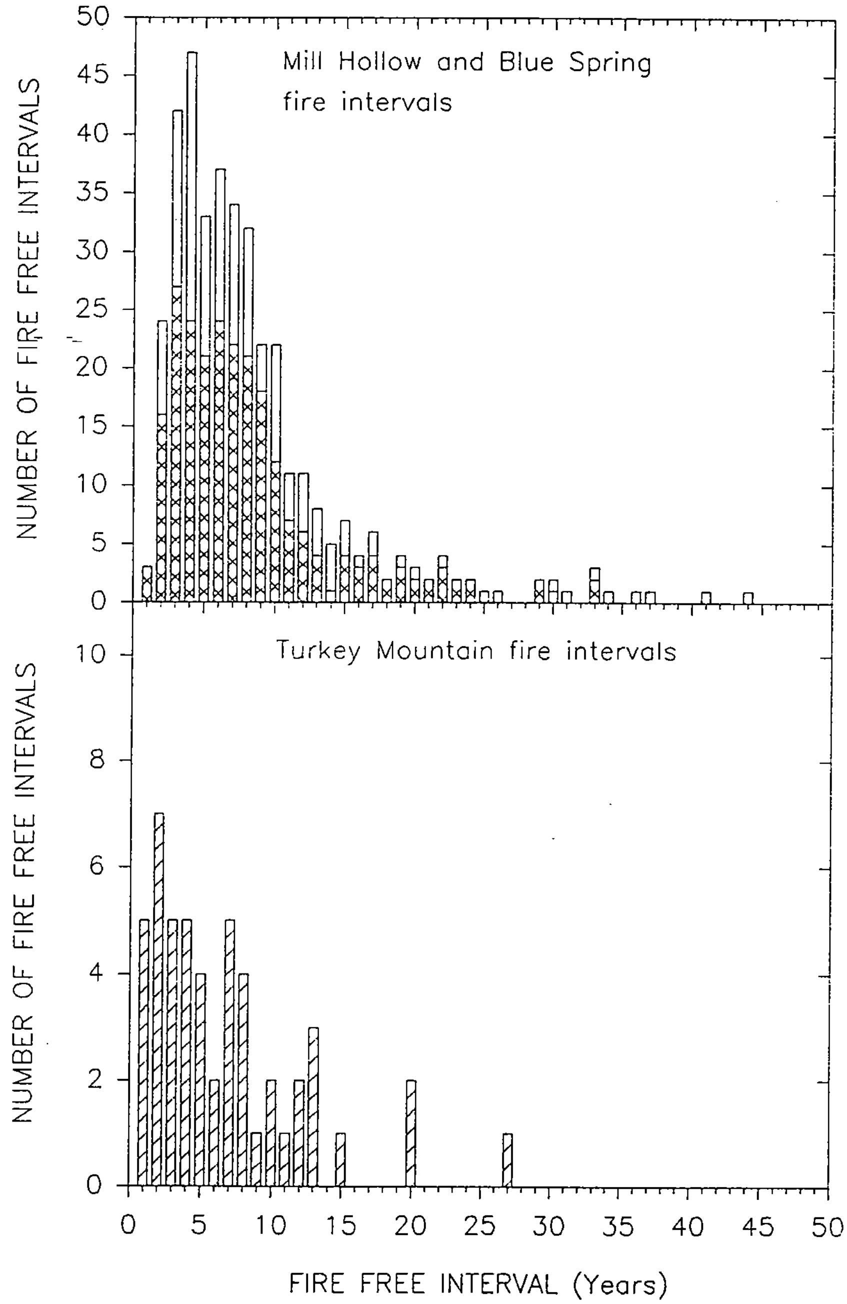

Figure 2. A comparison of fire free intervals from Turkey Mountain and two sites on the Current River.

Table 3. Comparison of sentinel pines from Turkey Mountain with sentinel pines from other oak-pine areas in the Ozarks. The fire interval is the average number of years between scars on a single sentinel pine.

SITE	# SCARS	PERIOD	MEAN FIRE FREE INTERVAL (yrs)
Turkey Mountain (Buffalo River)	31	1770-1967	6.4
Mill Hollow (Current River)	26	1719-1897	6.8
Trackler Mountain (Madison Co.)	36	1710-1915	5.7
Blue Spring (Current River)	27	1747-1887	5.2
Mill Mountain (Rocky Creek, Mo.)	25	1702-1831	5.2
Denning Hollow Glade (Rocky Creek)	18	1715-1898	9.7
Jerktail Mountain (Shannon Co.)	29	1708-1911	7.0
Crooked Creek (Douglas Co.)	13	1742-1916	5.6
Eck Tract (Big Piney River)	4	1814-1993	44.8

injury on the slow growing sentinel pine (TRK01). For the 1950's the dates are a best estimate. Only one fire, the 1953 fire, was replicated by other trees in the 1950's. Fire scar dates from all trees: 1804, 1806, 1812, 1821, 1832, 1845, 1850, 1857, 1862, 1866, 1878, 1882, 1885, 1889, 1890, 1892, 1894, 1900, 1906, 1909, 1915, 1922, 1924, 1932, 1934, 1936, 1940, 1943, 1948, 1949, 1950, 1951, 1953, 1954, 1955, 1956, 1960, 1963, 1971.

A Sentinel pine

These are individual shortleaf pines which have a special landscape position relative to fire behavior. Sentinel pines grow in lose gravel with very little local ground fuel. Despite the lack of ground fuel they have large multiple scars on the uphill side. They grow on the upper slopes of both cherty-dolomite and rhyolite substrate. Long slopes of 15 to 33 degrees with 200 to 800 feet of elevation typically lie below sentinel pine sites. Pre-heating, turbulence on the lee (uphill side) of the stem, slope-fire generated winds, and flame length at the top of the slope make initial scaring of this thick barked species likely. These trees are also particularly sensitive to scaring by later fires because of their slow growth. Slow growth, high oleoresin content, high xylem density, and a dry micro-climate, contribute to the preservation of these pine remnants. Because of their landscape position, sentinel pines are excellent recorders of the occurrence of fire in small watersheds.

Sample TRK01 was a sentinel pine which grew near the top of Turkey Mountain in a cherty soil with little ground cover or leaf litter. The tree had no canopy competition and grew in association with oaks. The landscape position of the tree made it a good recorder of fires ignited in Cook Hollow. Any fire in the valley was likely to end up at the at the top of Turkey Mountain because there are few large bluffs or other major fire breaks below the site, the site is at the apex of the dry south facing slope of the valley, and the 780 feet of elevation greatly increases the potential spread and the intensity of the fire as it reaches the site. This tree was a classic "sentinel pine".

The single shortleaf pine specimen has much fire history. There are, however, limits on what can be interpreted from a single tree. The sample has a fairly well preserved fire record from 1770 to the 1950's. Some small and older scars may have been burnt off the scar face. The tree had 31 fire scars. Scar removal by burning and the nearly annual scars of the 1950's make this total number approximate. Experience with callus tissue, cellular injury, and the distinctive creases in the charcoal face enabled the identification of old fire scars. Some facts and statistics on the site, fire scars and sentinel pine are:

1. Sample number: TRK01.
2. Collectors: R.P. Guyette and M.C. Lottes, June, 1993.
3. Species: shortleaf pine, Pinus echinata.
4. Location: Turkey Mountain, near Buffalo City, Arkansas.
5. Period of annual rings: 1770 to 1967.
6. Period of fire scar record:1770 to 1960.
7. Length of fire scar record: 190 years.
8. Number fire scars: 31.
9. Height of multiple fire scar face: 7 ft.
10. Mean fire free interval: 6.1 years.
11. Shortest fire free interval: 1 year.
12. Longest fire free interval: 34 years.
13. Periods of low fire frequency: 1815 to 1840.
14. Periods of high fire frequency: 1800 to 1821, 1930-1950's.
15. Site: elevation 1180 ft., aspect south, slope 23 degrees.
16. Tree description and history: The tree was a dead snag with some sapwood but no fine limbs or bark. Multiple fire scars (18) were observed on the uphill side of the bole. The scar face was 7 feet from the ground to the highest callus tissue on the stem. The pith date (@ 2 ft. on the stem) of the tree was 1770 indicating an age of approximately 200 years when it died in 1968. The tree grew slowly between 1770 and 1804 indicating there was competition at the site. At 34+ years of age, in 1804, the tree was released from competition by fire and more than doubled its ring width. Around 1943 the tree abruptly lost vigor and ring width decreased.

Fire extent

Data on the extent of recent fires was collected from 7 younger shortleaf pines. These trees (Figures 3,4,5,6) show that fires scarred pines in 1971, 1963, and 1953 growing on three sites: the eastern edge of Turkey Mountain where it borders the Buffalo River, the highest knob, and the western most knob of Turkey Mountain. The east-west distance between these sites of scarring is about 1.7 miles (2.5 km) with a vertical distance of over 550 feet. Thus, it is probable that Turkey Mountain burned from one end to the other at least 3 times in 18 years (1953-1971), plus burning in several other areas in the 1950's and in 1960 from the east end of the mountain to at least the highest knob. Given the steep slopes and southern exposures of Turkey Mountain, it is likely that the 1953, 1963, and 1971 fires, if not many others, burned at least a square mile.

Cultural influences

Cultural factors that potentially effect fires are: 1) land use, 2) human population, 3) and cultural change. Because the number of lightning ignitions in the Ozarks is very low relative to the number of ignitions from human sources, fire history is often intimately tied to human activity. Thus, gross population, land use, and cultural attitudes are important in determining the number and timing of ignitions (Table 4, Figures 7,8).

The confluence of large bodies of water is often an important geographic location for military and commercial activities, especially before road systems when rivers were the important means of transportation. Turkey Mountain lies at the confluence of the Buffalo and White Rivers, two early transportation corridors in an otherwise steep and difficult landscape for transportation. Consequently, Native American activity as well as the activity of early settlers, miners, and hunters might have been significantly greater around the Turkey Mountain area than at many of the more remote mountains of the region. The Old Buffalo Road which bordered the north and east sides of Turkey Mountain, the mine on Prince Fred knob, and an old foundation up Cook Hollow are recent examples of this activity. With this activity comes increased sources of ignition, both intentional and accidental. Human activity combined with pyrogenic characteristics of the Turkey Mountain landscape, such as high solar exposure and steep slopes, may have contributed to the creation and maintenance of the unique savannas on Turkey Mountain. Note that because of Stair Bluff on the north, only about 25% of the surface area of Turkey Mountain lies on the north side. This leaves about 75% of the land surface on the south side.

Table 4. Correlation coefficients among fires/decade and the population of Marion and Searcy Counties written as Pearson correlation coefficients / Probability > ¦R¦ under Ho: Rho=0/ number of observations.

	ALL DECADES (1770-1990)	MODERN FIRES (1950-1990)	EARLY FIRES (1770-1950)
POPULATION	0.42	-0.79	0.73
(probability	0.05	0.20	0.01
(n)	22	4	18

LANDSCAPE ANALYSIS FROM FIRE SCARS

The spatial analysis of tree scarring yielded excellent data on past fire intensity and frequency with respect to landscape variables such as elevation, aspect, vertical fetch (distance from the base of the slope), slope, and location. This data is used to create regression models which predict fire intensity as recorded by the percent of trees scarred. An evaluation of these variables and models for Turkey Mountain follows.

Elevation and vertical fetch

Elevation and vertical fetch were the most important variables effecting the percentage of trees scarred. Vertical

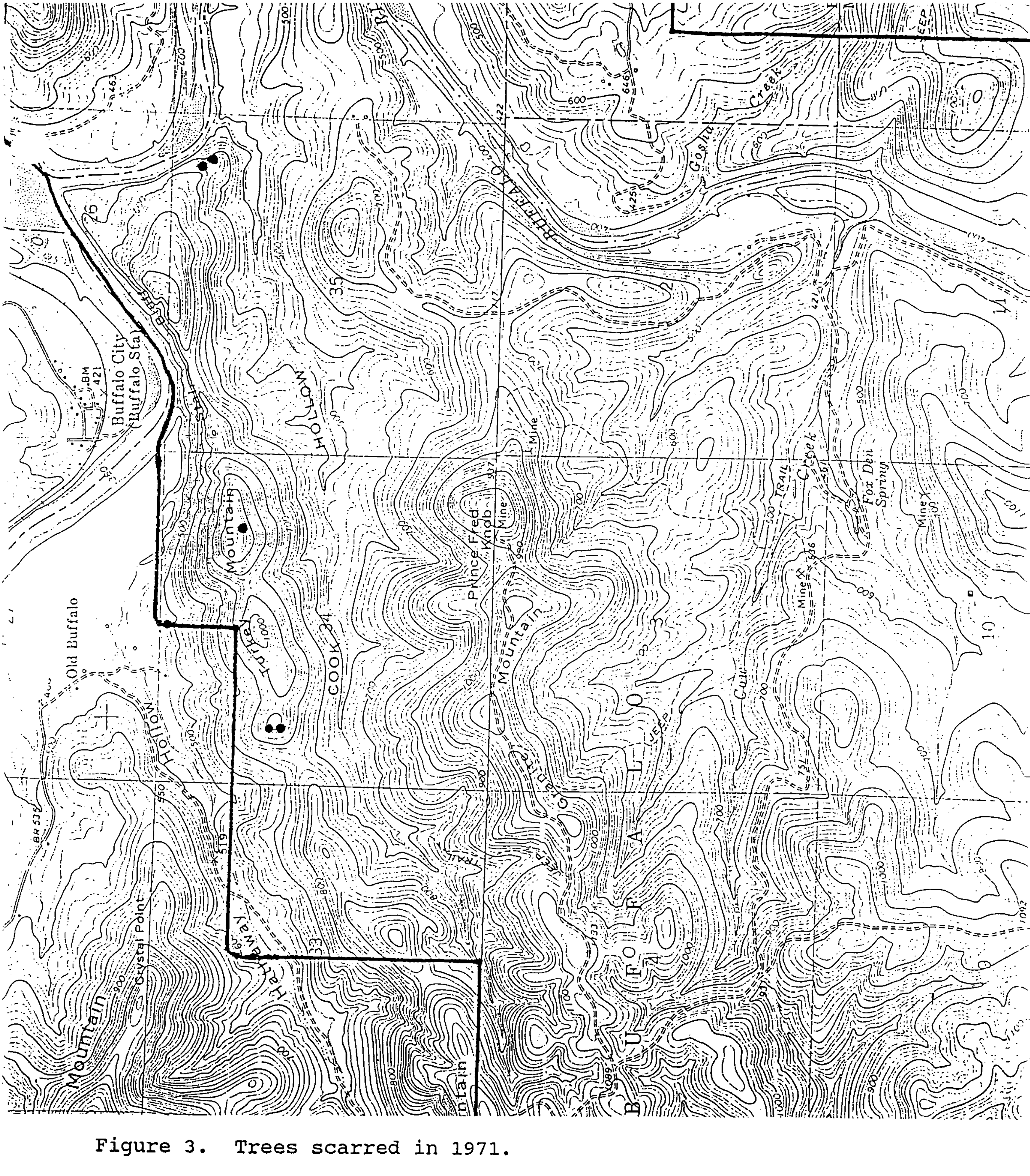

Figure 3. Trees scarred in 1971.

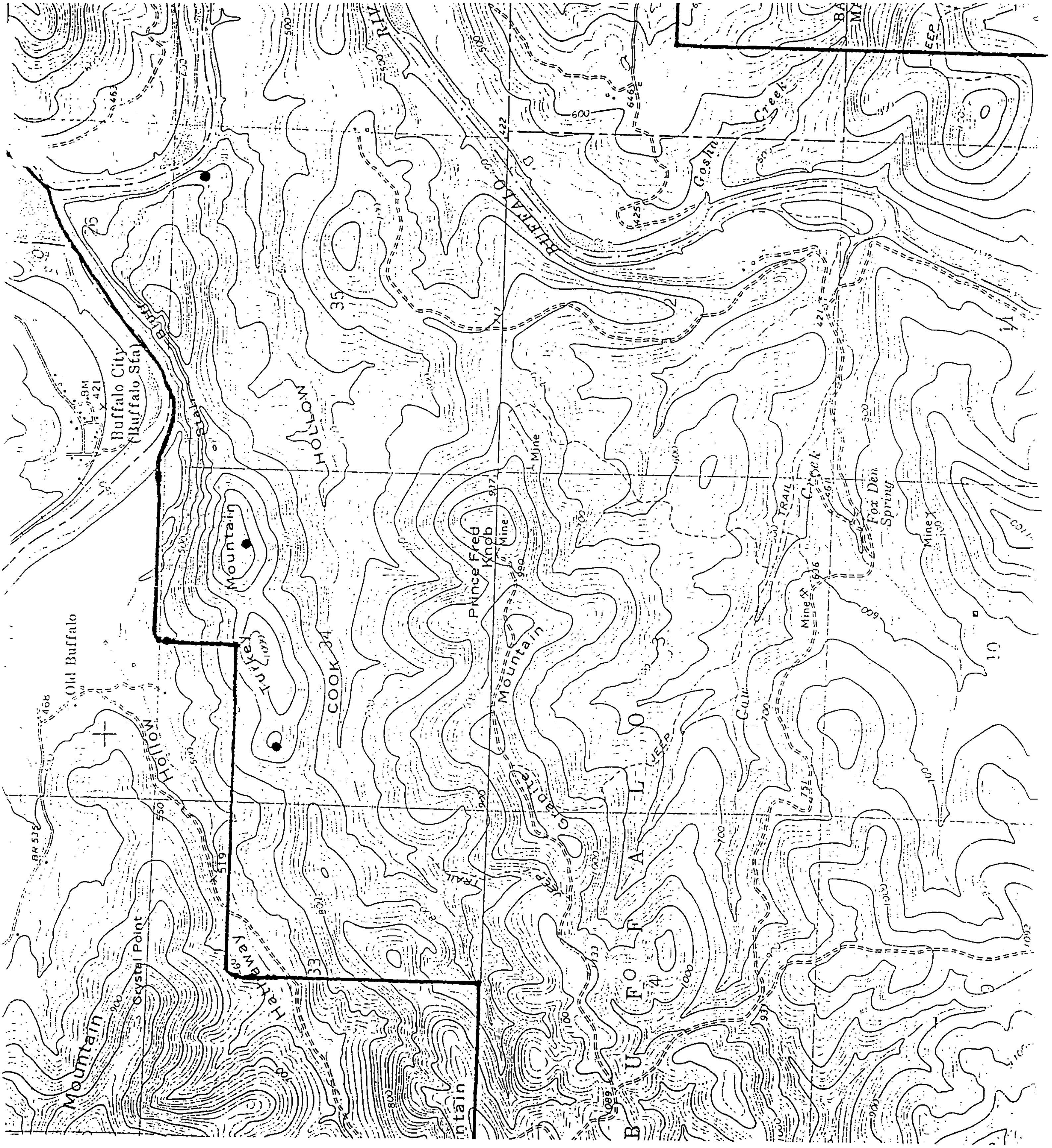

Figure 4. Trees scarred in 1963.

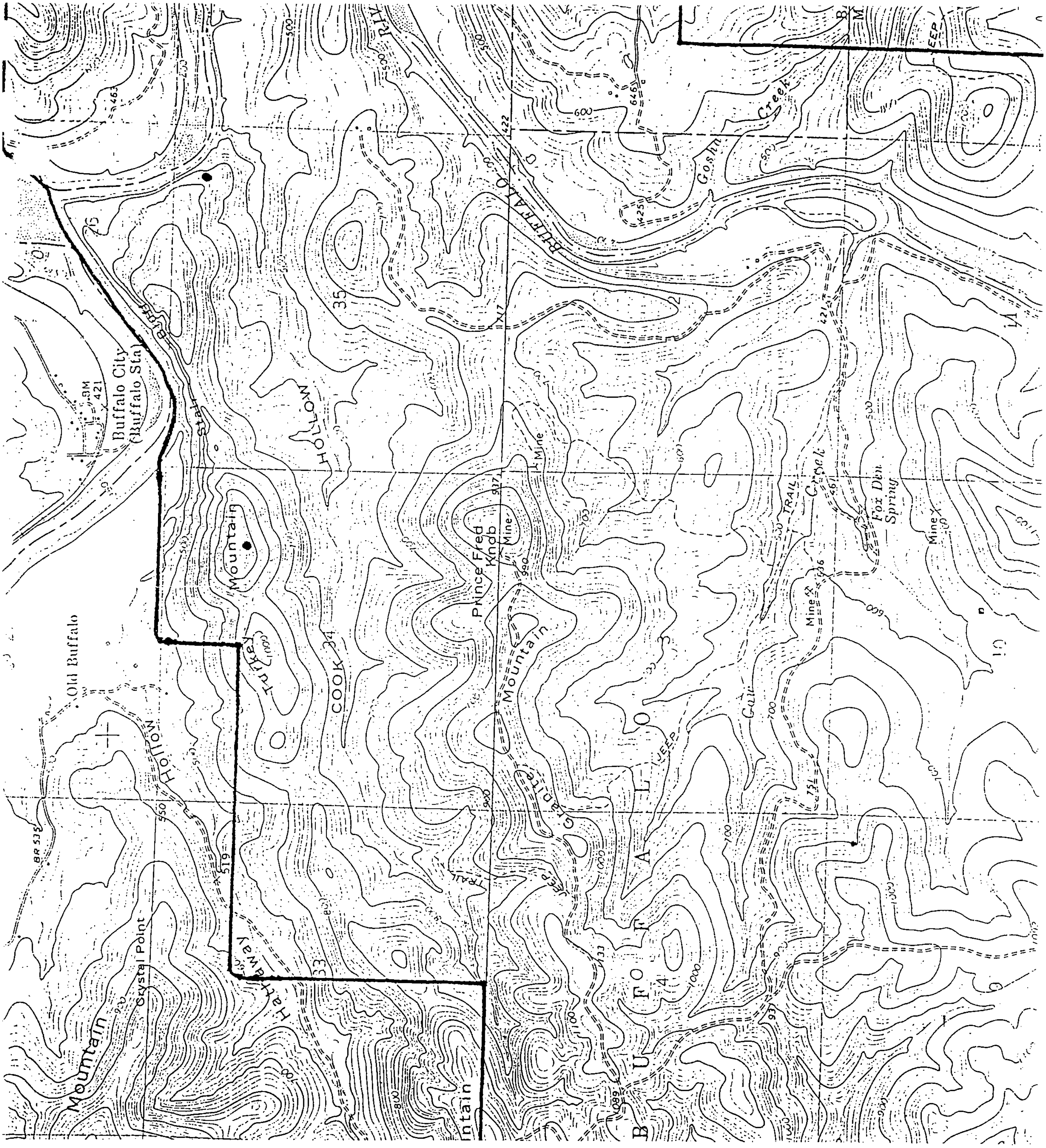

Figure 5. Trees scarred in 1960.

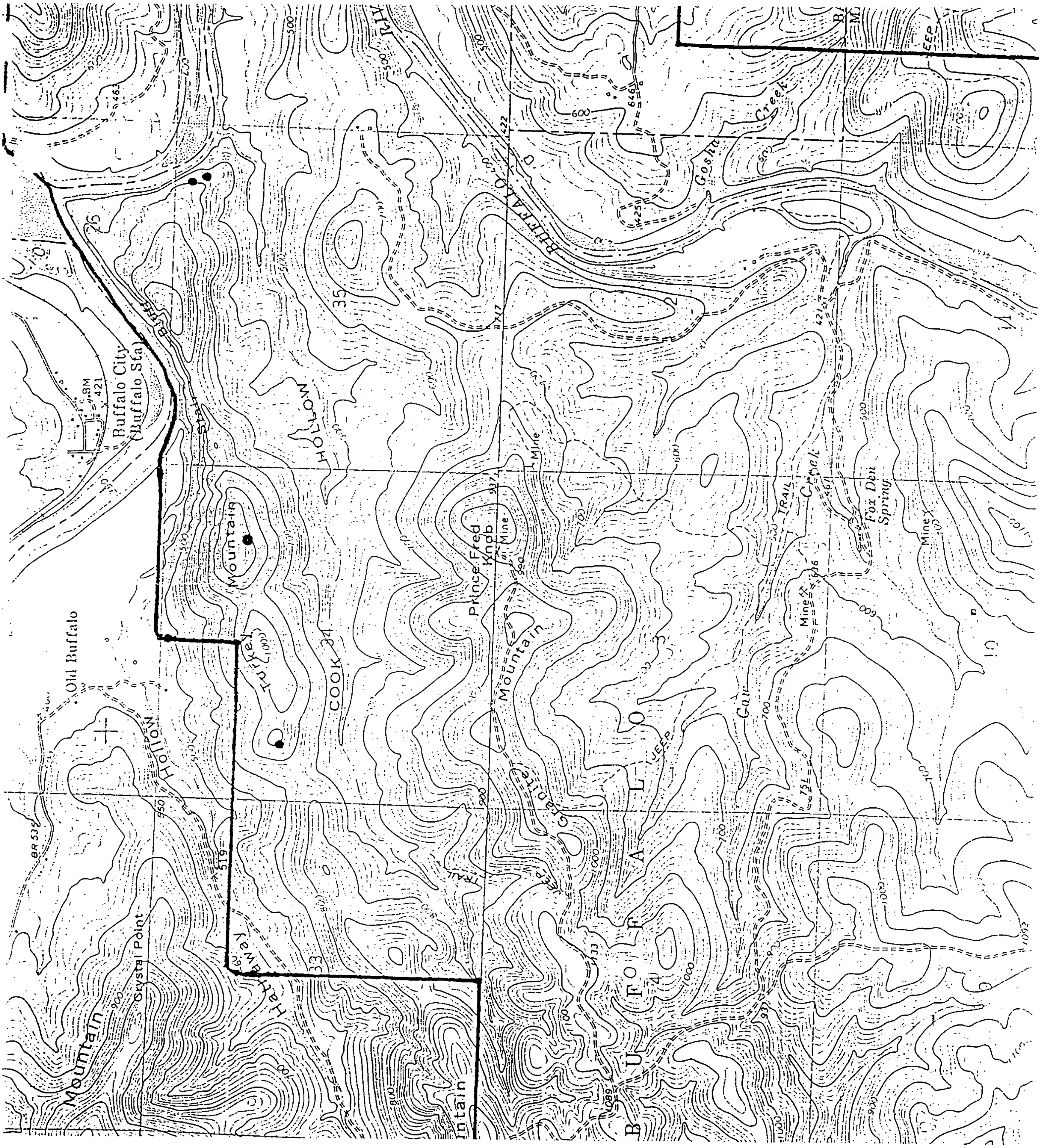

Figure 6. Trees scarred in 1953.

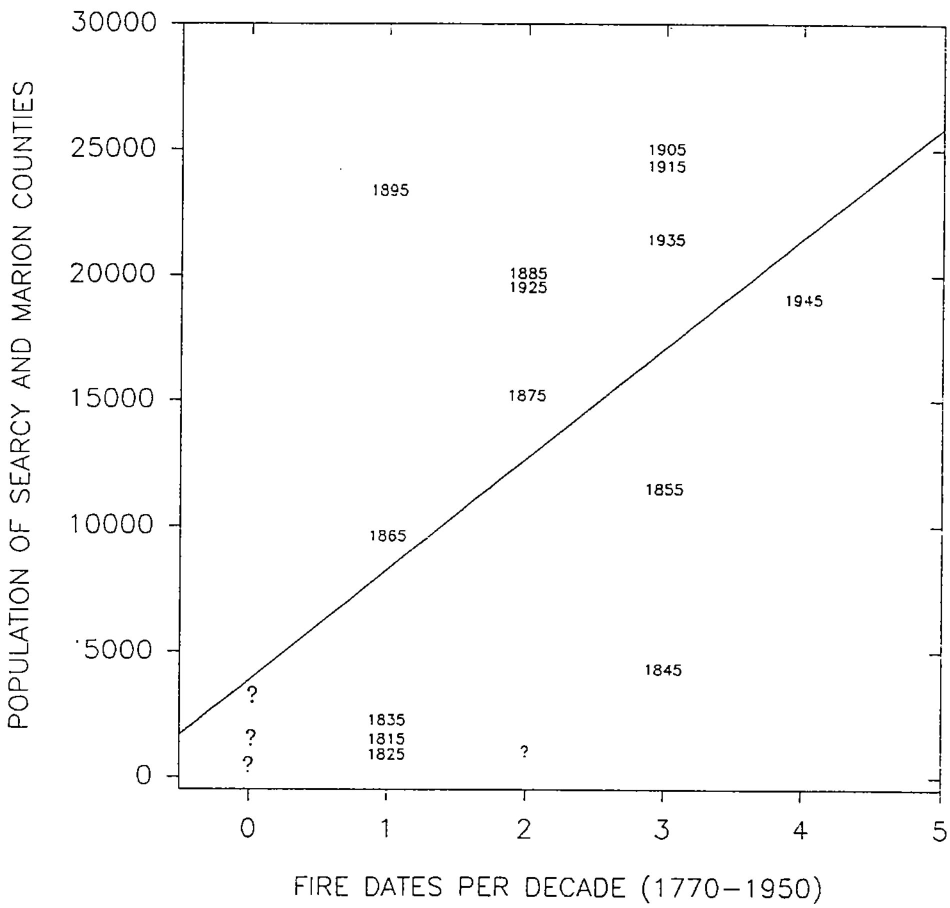

Figure 7. Early population (before 1950) of Searcy and Marion Counties plotted with the fire dates per decade on Turkey Mountain.

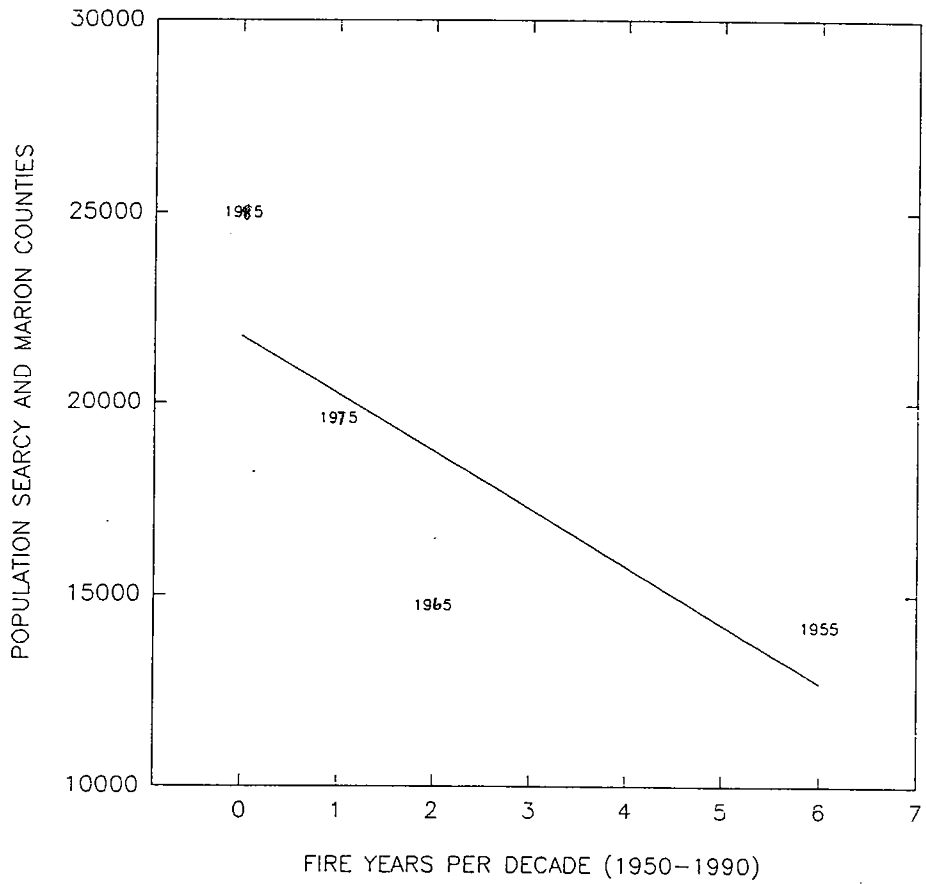

Figure 8. Recent population (after 1950) of Searcy and Marion Counties plotted with the fire dates per decade on Turkey Mountain.

Table 5. Correlation analysis of the percent trees scarred by aspect.

CORRELATION ANALYSIS AMONG % TREES SCARRED AND
ELEVATION, VERTICAL FETCH, SLOPE, ASPECT, SLOPE X ASPECT

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0
/ Number of Observations

SCARRED	% SCARRED ALL SLOPES	% SCARRED N SLOPES	% SCARRED E SLOPES	% SCARRED S SLOPES	% W SLOPES
ELEVATION	0.73431 0.0001 80	0.82193 0.0001 40	0.71378 0.0001 48	0.72475 0.0001 40	0.77563 0.0001 30
VERTICAL FETCH	0.68990 0.0001 80	0.78414 0.0001 40	0.69920 0.0001 48	0.68711 0.0001 40	0.67480 0.0001 30
ASPECT	0.40515 0.0002 80	0.41141 0.0084 40	0.59524 0.0001 48	-0.10037 0.5377 40	0.10668 0.5747 30
SLOPE	0.27948 0.0121 80	0.20739 0.1991 40	0.25223 0.0837 48	0.40119 0.0103 40	0.30453 0.1018 30
SLOPE X ASPECT	0.49060 0.0001 80	0.45043 0.0035 40	0.64517 0.0001 48	0.32552 0.0404 40	0.28841 0.1222 30

fetch is defined here as the distance from the base of the slope to the site. The height and length of slopes is known to be an important factor influencing fire intensity. Pre-heating by the vertical release of heat and the build up of slope generated thermal winds are a function of the length of the slope. Correlation among fetch, elevation, and the percentage of trees scarred (Table 5) ranged form 0.67 to 0.82. Elevation was more highly correlated with percent trees scarred than was fetch, indicating either autocorrelated site variables or that absolute elevation may be a minor factor in fire intensity. Both elevation and fetch were more highly correlated on north facing exposures than on south, east, or west exposures. Figure 9 illustrates the relationship between vertical fetch and the percent trees scarred for north (mean of plots from Transects 1,5,7,8) and south (mean of plots from Transects 2,3,4,6) slopes.

Aspect and exposure

Aspect is an important factor influencing fuel moisture and fire intensity. Both the maximum daily angle of incidence during the fire season and the length of solar exposure combine to reduce fuel moisture and pre-heat fuels. Significant correlations were found among aspects and the percentage of trees scarred, especially for northern and eastern facing slopes. The effect of aspect on the percent of trees scarred was between 4.5% and 18.1% and increased with slope. The means of the percent of trees scarred (Table 6) ranked by their solar exposure (EXP) are:

S slopes(52%) > W slopes(47%) > E slopes(43%) > N slopes(37%).

Slope

The degree of slope is a factor in fire intensity. Steep slopes allow the formation of micro-thermals, the upslope capture of the vertical release of heat, slope generation of winds, and increased angle of incidence during the spring and fall fire season. Slope was only weakly correlated with the percent of trees scarred (Table 5). The effect of slope on the percent of trees scarred was between 2.5% and 16.1% and increased with aspect (Table 7).

Slope and aspect interact to enhance pyrogenic characteristic such as solar exposure. Aspect was a more important factor influencing the percent trees scarred on the north aspects than was slope, slope was the more important on south aspects. Also the greater the slope the more effect aspect has on the percent of trees scarred. The interaction of slope and aspect (aspect X slope) was more highly correlated with the percentage of trees scarred than was either aspect or slope alone. For this analysis aspect is calculated as exposure (EXP=(|(|aspect-205|)-180|). This variable (SLOPExEXP) also preformed better in all regression models than either slope, aspect, or both.

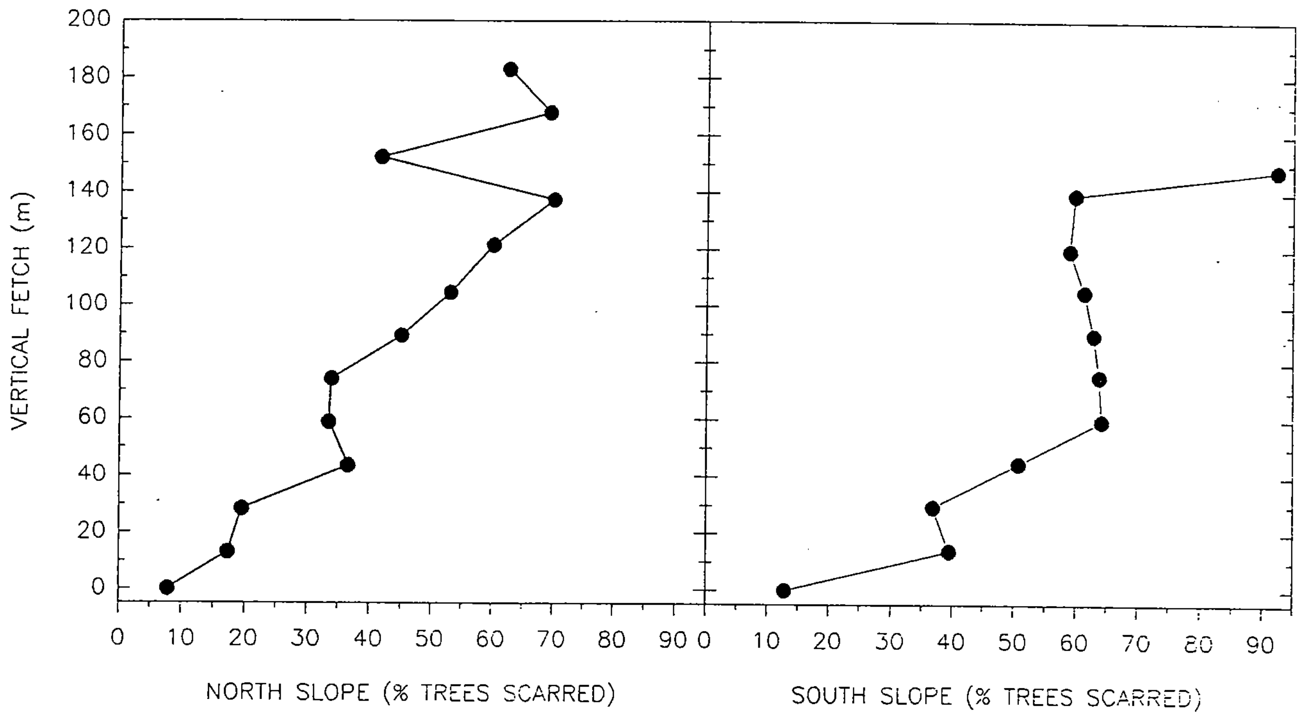

Figure 9. Comparison of averaged percent trees scarred from north (Transects 1,5,7, and 8) slopes and south (Transects 2,4,3,and 6) slopes.

Table 6. Simple statistics for percent trees scarred and independent variables.

SIMPLE STATISTICS FOR PERCENT TREE SCARRED

% TREES SCARRED BY SLOPE	N	Mean	Std Dev	Sum
% ALL SLOPES	80	44.30664	22.03718	3545
% NORTH SLOPE	40	36.88887	21.35187	1476
% EAST SLOPE	48	43.02739	20.92011	2065
% SOUTH SLOPE	40	51.72441	20.37046	2069
% WEST SLOPE	30	47.23750	24.03212	1417

Variable	N	Minimum	Maximum	Mean	Std Dev
TREES SCARRED	80	0	12.00	5.17	2.61
NUMBER TREES	80	5.0	23.00	12.43	3.90
SLOPE	80	0	29.00	17.97	6.66
ELEVATION	80	429	1040.00	714.38	155.49
ASPECT	80	0	320.00	170.93	98.45
VERTICAL FETCH	80	0	600.00	225.22	153.24

Table 7. Interactive effects of slope and aspect as calculated from the empirically derived model for Cook Creek (Equation 3). The example is calculated for sites 1 mile upstream with a 100 feet of vertical fetch.

PERCENT TREES SCARRED

	north aspect	south aspect	difference (south-north)
5 degree slope	22.9	27.4	4.5
10 degree slope	23.7	32.8	9.1
20 degree slope	25.4	43.5	18.1
difference (20-5 degrees)	2.5	16.1	

Distance from river

The percentage of trees scarred was a positively and significantly correlated with their distance from the rivers of their watershed. This was true for all plot transects ($r=0.38$ $p<0.0005$) as well as for those from only the Cook Creek watershed ($r=0.40$, $p<0.005$). Distance was measured from the mouth of Cook Creek on the Buffalo to the middle of a transect for the Cook

Creek watershed. When transects (5,6, and 8) from the White River watershed were included their distance was calculated from the White River (south side) near Buffalo City. The significance levels of these correlations as well as their performance in the models indicates a weak but pervasive causal factor. Note that there is about a 22% increase (Table 8) in fire scarring from the mouth of Cook Creek to its upper reaches (about 2.0 miles). Speculation as to causation:

1. Proximity to ignition sources along the river has decreased the fire free interval to well below the decay constant (years to equilibrium fuel build up) and enough to reduce fire intensity.

2. Proximity to ignition sources along the river has increased frequency enough to reduce fuel loading by altering vegetation structure (savannas?).

3. Fires from near river ignitions reached the upper Cook Creek in the afternoon and were more intense.

4. Distance from the river may be another expression of fetch or elevation on fire intensity. The difference in elevation from the mouth of Cook Creek on Buffalo River to the upper reaches of Cook Creek adjacent to Turkey Mountain is about 220 feet (480 ft to 600 ft) in about 1.8 miles.

Table 9. Correlation analysis of the percent trees scarred and distance from the White and Buffalo Rivers for all sites and for sites only in the Cook Creek Watershed and the distance from the Buffalo River.

ALL SITES (White and Buffalo Rivers)

	% SCARRED	DISTANCE
% SCARRED	1.00000 0.0	0.37998 0.0005
DISTANCE	0.37998 0.0005	1.00000 0.0

COOK CREEK SITES

	% SCARRED	DISTANCE
% SCARRED	1.00000 0.0	0.40398 0.0040
DISTANCE	0.40398 0.0040	1.00000 0.0

Bluff effect

Three high bluffs (> 20 feet) were encountered along the transects. Of these, two (Transects 5 and 6) showed a reduction in the percent of trees scarred just above the bluffs (Figure 10).

Models

Several regression models were developed from the data. These empirically derived models predict fire intensity from elevation, vertical fetch, exposure, and slope. The models can be used to test theoretically derived predictions. Here the models are developed for:

1. predicting fire intensity from landscape features,
2. correlation with savanna vegetation,
3. use with GIS systems
4. partitioning burn units.

Three models are presented here. Statistical details of the models are given in Tables 10,11,and 12.

1. %TRESCR = -40.6+(0.995*ELEV)+(0.00781*SLPxEXP)

2. %TRESCR = -0.277+(0.0983*FETCH)+(0.00608*SLPxEXP)+(15.03*DIST)

3. %TRESCR = -0.584+(0.0992*FETCH)+(0.00694*SLPxEXP)+(11.65*DIST)

where: %TRESCR = percent trees scarred
ELEV = elevation (feet)
SLPxEXP = slope x EXP (degree)
EXP= (|(|aspect-205|)-180|)
DIST = distance (miles)
Note: 205 degrees was choose as the aspect for maximum thermal exposure by iterations of the model.

All three models explain about the same amount of variance (73%, 74%, 75%) in the percentage of trees scarred. Models 1 and 2 are derived from all the sites whereas Model 3 is from data in the Cook Creek watershed only. Inputs to all models can be derived from topographic maps, digitized or not. The models can be used to predict fire intensity and define fire units from landscape features. Model 1 is limited to the Turkey Mountain Site because of the elevation input which would only transfer to sites of with similar elevations. Models 2 and 3 are more general but probably limited to near river areas. Also, vertical fetch has to be calculated from a topographic map for input. However, it is probably fetch and not absolute elevation which is the important variable.

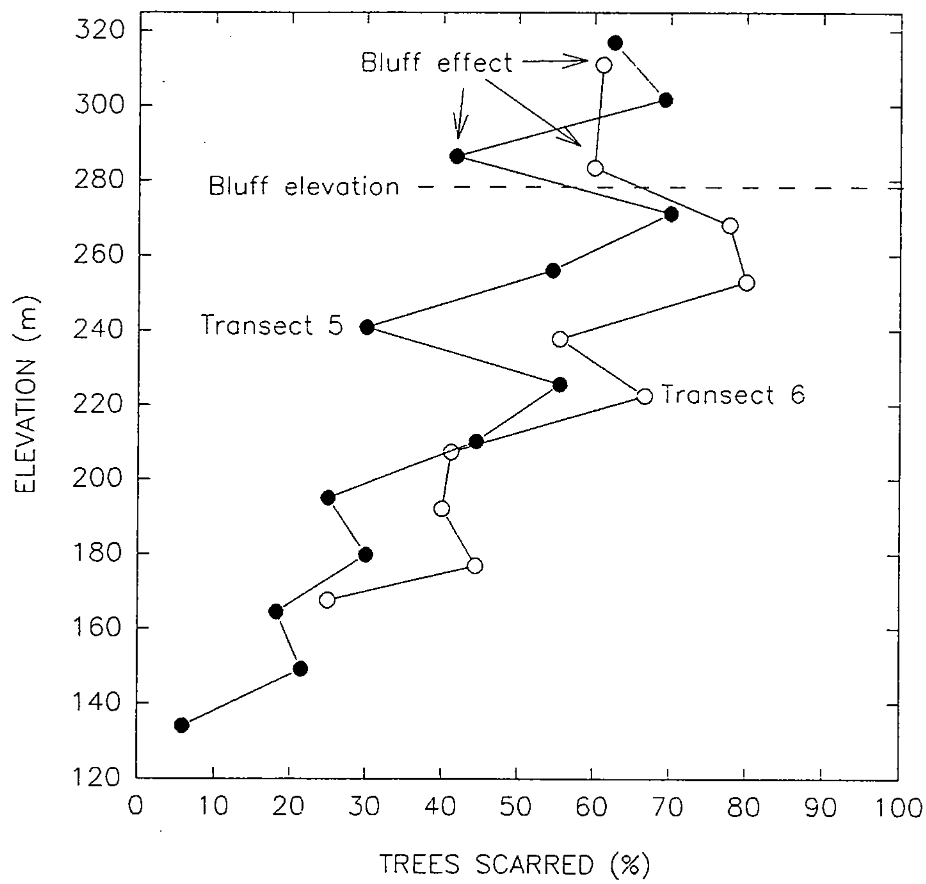

Figure 10. Bluff effects on the percentage of trees scarred.

Table 9. Selected model calculations (Equation 3, derived from Cook Creek data) predicting the percent trees scarred by iterations of: 1) distance, 2) slope and aspect, 3) vertical fetch for ranges scaled to Cook Creek.

1. Iterations of distance (from the mouth of Cook Creek):

TREES SCARRED (%)	FETCH (feet)	SLOPE (degrees)	ASPECT (degrees)	EXPOSURE	DISTANCE (miles)
37.5925	200	15	180	2325	0.1
42.2325	200	15	180	2325	0.5
48.0325	200	15	180	2325	1.0
53.8325	200	15	180	2325	1.5
59.6325	200	15	180	2325	2.0

2. Iterations of slope and aspect as exposure:

TREES SCARRED (%)	FETCH (feet)	SLOPE (degrees)	ASPECT (degrees)	EXPOSURE	DISTANCE (miles)
22.9180	100	5	1	120	1.0
22.7800	100	5	45	100	1.0
24.3325	100	5	90	325	1.0
25.8850	100	5	135	550	1.0
27.4375	100	5	180	775	1.0
27.6100	100	5	225	800	1.0
26.0575	100	5	270	575	1.0
24.5050	100	5	315	350	1.0
23.7460	100	10	1	240	1.0
23.4700	100	10	45	200	1.0
26.5750	100	10	90	650	1.0
29.6800	100	10	135	1100	1.0
32.7850	100	10	180	1550	1.0
33.1300	100	10	225	1600	1.0
30.0250	100	10	270	1150	1.0
26.9200	100	10	315	700	1.0
25.4020	100	20	1	480	1.0
24.8500	100	20	45	400	1.0
31.0600	100	20	90	1300	1.0
37.2700	100	20	135	2200	1.0
43.4800	100	20	180	3100	1.0
44.1700	100	20	225	3200	1.0
37.9600	100	20	270	2300	1.0
31.7500	100	20	315	1400	1.0

3. Iterations of vertical fetch:

TREES SCARRED (%)	FETCH (feet)	SLOPE (degrees)	ASPECT (degrees)	EXPOSURE	DISTANCE (miles)
22.9840	1	10	180	1550	1.0
23.3800	5	10	180	1550	1.0
23.8750	10	10	180	1550	1.0
37.7350	150	10	180	1550	1.0
42.6850	200	10	180	1550	1.0
52.585	300	10	180	1550	1.0
62.485	400	10	180	1550	1.0
72.385	500	10	180	1550	1.0
82.285	600	10	180	1550	1.0

Table 10. Model 1 explaining percent trees scarred on all sites by elevation and the interaction of slope and aspect (south exposure).

General Linear Models Procedure

Number of observations in data set = 80

MODEL:

% TREES SCARRED = -40.6+(0.995*ELEVATION)+(0.00781*SLOPExEXPOSURE)

Dependent Variable: % TREES SCARRED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27931.12409	13965.56204	103.06	0.0001
Error	77	10434.21415	135.50927		
Corrected Total	79	38365.33824			

R-Square	C.V.	Root MSE	% SCARRED Mean
0.728030	26.27336	11.64085	44.3066428

Source	DF	Type I SS	Mean Square	F Value	Pr > F
ELEVATION	1	20687.19096	20687.19096	152.66	0.0001
SLOPExEXPOSURE	1	7243.93312	7243.93312	53.46	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
ELEVATION	1	18815.36669	18815.36669	138.85	0.0001
SLOPExEXPOSURE	1	7243.93312	7243.93312	53.46	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-40.63162197	-6.42	0.0001	6.32448215
ELEVATION	0.09952070	11.78	0.0001	0.00844582
SLOPExEXPOSURE	0.00781138	7.31	0.0001	0.00106838

Table 11. Model 2, an alternative model explaining percent trees scarred on all sites by vertical fetch (elevation from base of slope), the interaction of slope and aspect (south exposure), and the distance of the site from either the White or Buffalo Rivers by respective watershed.

General Linear Models Procedure

Number of observations in data set = 80

MODEL:

% TREES SCARRED=-0.277+(0.0983*V.FETCH)+(0.00608*SLOPExEXP.)+(15.03*DISTANCE)

Dependent Variable: % TREE SCARRED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	28400.70554	9466.90185	72.20	0.0001
Error	76	9964.63270	131.11359		
Corrected Total	79	38365.33824			

R-Square	C.V.	Root MSE	% SCARRED Mean
0.740270	25.84372	11.45048	44.3066428

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VERTICAL FETCH	1	18260.32884	18260.32884	139.27	0.0001
SLOPExEXPOSURE	1	7807.09351	7807.09351	59.54	0.0001
DISTANCE TO RIVER	1	2333.28320	2333.28320	17.80	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VERTICAL FETCH	1	17793.84780	17793.84780	135.71	0.0001
SLOPExEXPOSURE	1	3649.80169	3649.80169	27.84	0.0001
DISTANCE TO RIVER	1	2333.28320	2333.28320	17.80	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.2768943130	-0.08	0.9379	3.54127326
VERTICAL FETCH	0.0983434054	11.65	0.0001	0.00844178
SLOPExEXPOSURE	0.0060840230	5.28	0.0001	0.00115313
DISTANCE TO RIVER	15.03735907	4.22	0.0001	3.56576599

Table 12. Model 3, a Cook Creek alternate model explaining percent trees scarred on all sites by vertical fetch (elevation from base of slope), the interaction of slope and aspect (south exposure), and the distance of the site from the Buffalo River.

General Linear Models Procedure

Number of observations in data set = 49

MODEL:

% TREES SCARRED=-0.584+(0.0992*V.FETCH)+(0.00694*SLOPExEXP.)+(0.174*DISTANCE)

Dependent Variable: % TREES SCARRED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	17638.64550	5879.54850	45.45	0.0001
Error	45	5821.57012	129.36822		
Corrected Total	48	23460.21562			

R-Square	C.V.	Root MSE	% SCARRED Mean
0.751854	24.02881	11.37402	47.3349042

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VERTICAL FETCH	1	11136.57715	11136.57715	86.08	0.0001
SLOPExEXPOSURE	1	5476.90559	5476.90559	42.34	0.0001
DISTANCE TO BUFFALO R.	1	1025.16275	1025.16275	7.92	0.0072

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VERTICAL FETCH	1	9804.317951	9804.317951	75.79	0.0001
SLOPExEXPOSURE	1	3638.787030	3638.787030	28.13	0.0001
DISTANCE TO BUFFALO R.	1	1025.162749	1025.162749	7.92	0.0072

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	0.5839413022	0.12	0.9026	4.74665246
VERTICAL FETCH	0.0991891366	8.71	0.0001	0.01139382
SLOPExEXPOSURE	0.0069445423	5.30	0.0001	0.00130942
DISTANCE TO BUFFALO R.	11.65627903	2.81	0.0073	4.14811332